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DESIGN OF A BIOGAS GENERATOR FOR USE IN SEMIARID REGIONS

M.B Oumarou and Dauda M
Mechanical Engineering Department, University of Maiduguri, Bornu State

ABSTRACT
Biomass is a form of renewable and sustainable energy source with the highest potential to contribute to the energy needs of modern society for both the developed and developing countries. However, its usage in form of biofuels is still in the preliminary stage. There is a need to identify a suitable biofuel in terms of availability, which can provide high-energy output to supplement the rapidly depleting fossil fuels. Animal wastes are rich sources of energy and they are abundantly found in the semiarid regions. The energy from the waste material is extracted by anaerobic digestion of the organic matter by bacteria. This paper covers the design, cost analysis, construction and testing of a family size biogas plant for use under local conditions, and safety features for the prospect of large biogas production in semi arid regions. Plants were constructed and tests were conducted at the workshop of the University of Maiduguri in Nigeria; and the gas produced was found to be burning cleanly with almost no noticeable flame if not for the heat being released. Soot formation was reduced and smoke emission was quasi inexistent.

KEYWORDS: Biomass, Animal waste, sustainable energy, anaerobic digestion, semiarid region.

INTRODUCTION

Over the centuries, various sources of energy have been used by man in order to meet his basic life-essentials such as food, water and shelter. Starting with his own energy and sun light, he progressed to fuel wood, draft-animal power, water and wind power, then developed engine fueled by wood, coal, etc. Fossil fuels provide the bulk of the world's primary energy (i.e.: 77% fossil fuels, 18% renewable and 5% nuclear power) (Pickering and Lewis, 1995), thus the world, is seeking new energy sources as alternative to fossil fuels. To that effect, experts believe that crude oil, providing at present more than one –third of the world energy needs will gradually lose its supremacy and recourse to other energy will become necessary as it becomes scarcer (Rival, 2005).

Today, climate change is everyone's concern and it is among the common borderless problems if not the only one linking the international community and drawing much attention. Many countries are faced with energy and safe drinking water problems ranging from unavailability to resulting environmental effects and several governments have planned policies aimed at solving the problem. In Nigeria, northern Cameroon, Niger republic, among others, fuel wood, petroleum, gas, kerosene and electricity constitute important sources of energy. However, the majority of the populations living in rural areas do not have access to gas or electricity (Abubakar, 1990). Also, 75% of the population in developing countries are in rural areas and are illiterate or semi literate and broadly depend on fuel wood for daily cooking and kerosene for lighting. To this should be added the fact that semiarid regions are characterised by yearly rain falls of 125 to 500 millimetres (mm) and average daily temperatures of 40~45^{o}C (SFSA 2007), which corresponds to the mesophilic temperature range.

With the excessive use of wood, smoke production is also excessive. Smoke is mainly carbon dioxide (CO_2) and carbon monoxide (CO) for incomplete combustion, therefore resulting in health effects, such as changes in relative brightness threshold and visual acuity, effective paralysis of cells of our lungs, etc (Pruss *et al*. 1999). More than two billion people globally use biomass for cooking food. Smoke from burning biomass is one of the fourth leading causes of death and disease in the world's poorest countries (WHO 2002).

Akinbami *et al.* (2001) identified feedstock substrate for an economically feasible biogas programme including water lettuce, water hyacinth, dung, cassava leave, urban refuse and agricultural residue. Also, they arrived at 227,500 tonnes of fresh animal wastes production daily and believe that the biogas production may therefore be a profitable means of reducing or even eliminating the menace and nuisance of wastes in many cities.

The development of new methods of production and use of renewable energy sources that suit the economic and geographical conditions of the developing countries will be required in order to solve these problems. The 1975 global energy crisis also has generated interest in the use of animal waste as energy substitute to fossil fuel (Pickering and Lewis, 1995). Production of fuel gas (methane) from animal waste in an oxygen free atmosphere is one of the important possible alternatives and could go a long way in preventing deforestation through indiscriminate cutting of trees.

The first application of the system was in the natural decay of human excreta in earth closets, but having observed the overall process, men provided conditions in which the process could be more optimized in the septic tank and variations of this. Numerous design alternatives and combinations are available for anaerobic digestion; Indian Gobar Digester or the Floating Gas-Holder type, the Chinese Digester or the Fixed Dome type (Nijaguna, 2006) as well as many hundreds of large mechanized, heated anaerobic digesters.

Therefore, the aim and objective of this work is to protect the environment through appropriate waste utilization by designing and testing a biogas digester using locally-available material for the purpose of producing sustainable energy from wastes.

MATERIALS AND METHODS

Animal wastes (cow dung), used drums and galvanized pipes are used in this work. The drums, pipes and other items were joined through welding and other joining processes, in the university of Maiduguri engineering workshop.

Animal wastes vary in chemical composition, physical form and quantities produced, mainly due to the variability in the digestive physiology of the various species, the composition and form of diet as shown in table (1) (Aliyu *et al*,1996).

Table 1: Average gas yield and C: N ratio for various species

Substrate	*Average gas yield (kg volatile solids)*	C:N (ratios)
Cow	250	10-30
Swine manure	450	9.13
Poultry manure	460	5.8
Sheep manure	200	30
Horse manure	220	

Biogas composition varies from 50% Methane- 50% Carbon dioxide to about 80% Methane with some hydrogen, nitrogen and other traces. A C: N ratio of 30:1 is optimum for biogas production (Abubakar, 1990). A combination of cow dung and poultry droppings (mixed in a ration of 2:1 w/w) gives the highest volume of gas (Aliyu *et al.* 1996).

Anaerobic breakdown of waste occurs at temperatures lying between 0^oC and 69^oC, but the action of the digesting bacteria will decrease sharply below 16^oC. Production of gas is more rapid between 21^oC and 41^oC or between 41^oC and 60^oC. This is due to the fact that two different types of bacteria multiply best in these two temperature regimes, but the high temperature dependant bacteria are much more sensitive to ambient influences (Peter *et al.* 1993).

Biogas production starts with the Insoluble biodegradable stage, Acid forming stage and ends with the Methane forming stage. The general equation for anaerobic digestion is:

$$C_xH_yO_z + \left(x - \frac{y}{4} - \frac{z}{2}\right)H_2O \rightarrow \left(\frac{x}{2} - \frac{y}{8} + \frac{z}{4}\right)CO_2 + \left(\frac{x}{2} + \frac{y}{8} - \frac{z}{4}\right)CH_4 \qquad \text{\_\_\_\_\_\_\_ (1)}$$

For cellulose, this becomes:

$$(C_6H_{10}O_5)_n + nH_2O \rightarrow 3nCO_2 + 3nCH_4 \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \ (2)$$

To facilitate optimum efficiency of production, conditions in the digester should be favourable to the bacteria evolved. Factors such as the nature of the organic waste, temperature, mixing, loading rates, water content, pH, air tightness, toxic substances, catalysts and retention time are known to affect plant performance. The latter is the most single indicator of performance and is evaluated as:

$$t_r = {V_d}/{\dot{V}_f} \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \ (3)$$

t_r ________________retention time in days or hours

V_d _______________ Volume of the digester-litres (l)

$\dot{V}_f$ _______________ daily feed rate l/day

Carbon dioxide can be removed by provision of water-carbonation tank- in which the biogas is allowed to bubble through water since the latter dissolves CO_2 (Martyn, 1994), as shown below:

$$CO_2 + H_2O \rightarrow H_2CO_3 \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \ (4) \text{ slow}$$

Methane is a colourless, odourless gas which burns in air. However, it is associated with risks because suffocating if it replaces much of the air in a confined place. Some of constituents particularly hydrogen sulphide, are extremely poisonous at concentrations of few ppm (Aarne *et al.* 1988). To this effect, Tertiary-butyl mercaptan $(CH_3)_2CSH$, 2 metyl-2 propane- thiol is added in trace amount (CGA, 1990) to serve as odorant to prevent against risk of fire from leaks. Furthermore, catalysts such as nickel, nickel-molybdate can help in upgrading methane's purity. Iron oxide is a low cost material and has a high sulphur absorption capacity (Martyn, 1994). Iron or Zinc oxides can be used

$$Fe_3O_4 + H_2 + 3H_2S \rightarrow 3FeS + 4H_2O \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \ (5)$$

and $ZnO + 4H_2S \rightarrow ZnS + H_2O$ ________________________ (6)

Design

Anaerobic digestion is essentially a self-controlling process once the digestion has been started and basic conditions met. The experimental set up consists of, primarily a tank, the digester containing the mixture of animal waste and water, and secondly another tank containing water and serving as gas-holder. Livestock wastes also vary in chemical composition and physical form. Hence, wastes from different species of animals have different physical characteristics. Thus, wastes from sheep, horse and poultry contain less moisture than dairy and beef wastes. This is due to difference in the physiological mechanisms for water retention and excretion in the various species. However, a combination of wastes from various animals may be preferred (e.g.: cow dung-poultry droppings; goat manure-cow dung; etc). Table (2) shows the characteristics and estimations of gas production from various animals (Nijaguna, 2006).

Table 2: Characteristics and estimations of gas production from various animals.

	Dairy cattle	Beef cattle	Swine	Poultry
Manure production (kg/day)	39	26	23	27
Total solids (kg/day)	5	3.5	3	8
Volatile solids (kg/day)	4	3	3	6
Digestive efficiency (% of VS)	35	50	55	65
Biogas production ($m^3 kg^{-1}$ VS added)	0.3	0.41	0.5	0.53
(m^3/454 kg animal day)	2.53	2.44	2.67	6.87

The Digester

It is made of a drum 150 cm long and 59 cm in diameter. The length is obtained after welding a full drum of 90 cm together with part of another drum of equal size. The bolts and nuts of the digester top are mounted prior to welding. A conical plastic funnel, connected to the digester by a plastic tube, 8 cm diameter, fixed at 10 cm from the bottom of the digester and serves as inlet pipe for the slurry. Opposite to it, a 6 cm steel pipe is welded; draining to the outside at the base of the digester serves as an outlet for the digested sludge. At the 2/3 of the total length of the digester from the bottom, a tap of small outlet diameter is provided and serves as an outlet for the slurry and a level-metre for the mixture not to exceed the desired level.

Volume of the digester; V_d

$$V_d = \pi d^2 L / 4 \qquad \text{(7)}$$

The volume occupied by the fluid; V_{oc}

$$V_{oc} = \frac{2}{3} V_d \qquad \text{(8)}$$

The volume of fluid in the inlet pipe; Vpipe

$$V_{pipe} = (0.82 + 0.21) \times 3.14 \times (0.08)^2 / 4 = 5.174 \times 10^{-3} m^3$$
$$V_{pipe} = 5.174 \times 10^{-3} m^3 \qquad \text{(9)}$$

The total volume of fluid in the digester; V_f

$$V_f = V_{oc} + V_{pipe} \qquad \text{(10)}$$

This is a capacity of 278 litres of slurry.

The quantity of waste needed for the initial feeding; M_0

$$V_f = M_0 / \rho_m \Rightarrow 0.278 m^3 = M_0 / 50 kg/m^3 \qquad \text{(11)}$$

Feeding the digester daily with 15 litres of slurry say 750 grams of waste, the retention time; t_r; will be:

$$V_d^* = \dot{V}_f \times t_r \Rightarrow t_r = V_d^* / \dot{V}_f \qquad \text{(12)}$$
$$\Rightarrow t_r = 18 days$$

The volume of biogas produced on daily basis; V_b

$$V_b = c m_0^* \qquad \text{(13)}$$

c- Biogas yield per unit dry mass of whole input ($0.4m^3/kg$)
*m_{0}- mass of daily dry input.

$$V_b = 0.3m^3 day^{-1}$$

Also, the thickness of the digester wall can be estimated. The yield stress of mild steel used in making drums is σ=230 MN/m^2 (Avalone and Baumeister, 1996). Assuming the digester is fully loaded with waste –water mixture, the minimum thickness will be.

$$\sigma = {}^{pd}\!/_{2t} \Rightarrow t = {}^{pd}\!/_{2\sigma} = 1.5 \times 9.80 \times 10^3 \times 230 \times 10^6 \times {}^{0.59}\!/_{2}$$

$$= 1.88 \times 10^{-5} m \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ (14)}$$

$$t_{\min} = 0.019mm$$

The Gas-holder

This is the most important part of the biogas plant. Gas is stored in the drum and taken off from the top through a tap for use. Because of fluctuations in rate of gas production and often of utilization, the pressure on the water may increase or decrease. The gas reservoir is made of a drum of dimensions 90 cm length and 59 cm in diameter containing water.

The water in the gas-reservoir will scrub impurities from the gas, hence should be changed after some few years. Since carbon dioxide is transformed into carbonic acid when dissolved in water, the volume of water needed can be estimated from equation (4);

$$CO_2 + H_2O \rightarrow H_2CO_3(aq) slow$$

Making a volume to weight analysis, 22.4 litres of CO_2 need 18grams of H_2O to transform into H_2CO_3. And the lowest Methane: Carbon dioxide ratio in the biogas is 50% each, say 0.15 m^3 thus giving 150 litres of CO_2.
The daily water requirement

$$x = 150 litres \times {}^{18grams}\!/_{22.4litres} = 120.53 grams.of.H_2O \approx 121 grams$$

$$say 0.121 litres day^{-1}$$

If the gas-reservoir is to be filled to the 50 cm level, the volume of water; Vw, to be used will be:

$$V_w = 3.14 \times \frac{(0.59)^2}{4} \times 0.5 = 0.13662 m^3$$

$$say \approx 137 litres$$

$$V_w = 137 litres$$

Since 0.121 litres is the daily water requirement, and considering a calendar year or 365 days, the time after which the water may be changed can be estimated as t.

$$t = \frac{137 litres}{0.121 litres day^{-1}} \approx 1132 days \approx 3.10 years$$

$$t = 3 years.under."prefect".conditions.$$

It should be noted that the Carbonic acid, H_2CO_3 produced is a very weak acid which is not dangerous to lives.

Cost Analysis

Cost had always been an important aspect of a project. It determines the affordability and sometimes the viability which is a quality dependent parameter. Since costs are subject to timely fluctuations, the analysis may only be useful for the present. In the future, increases in cost may occur.

DISCUSSION OF RESULTS

The biogas digester was constructed using a drum of 90 cm length and 59 cm diameter. The initial loading was done with 140 litres of slurry while the gas holder was filled with 190 litres of water. The daily temperature recorded was 40^oC. The system was left for 8 days before noticing an increase in volume and sounds in the gas holder after opening the transfer tap at the top of the digester. Several flammability tests were conducted at the workshop of the University of Maiduguri in Nigeria; and the gas produced was found to be burning cleaning with almost no noticeable flame if not for the heat being released. The production continued for 15 consecutive days, but at a reducing rate since no loading was carried out after the initial one.

Major leakages were observed through the mixing device. Its removal and closure of the orifice through which it passed, eliminated completely the leakages. Loading was done henceforth with fresh cow dung which was far easier to offload.

CONCLUSION

a. A biogas digester was successfully constructed and tested. The biogas production was noticed after 8 days through an increase of volume in the digester and sounds.
b. The gas was found to be burning cleanly without noticeable smoke.
c. Construction costs were affordable and found to be around =N= 13,475.00 ($ 100.00) for a family of four (4) biogas digester.
d. However, problems such as leakages through the mixing device and off loading of the digested material in the case of loading with dried cow dung were observed.
e. There is need to make corrections on the present design, and alternative materials need to be looked into to lower the cost further.
f. Replacement with the fresh or mixed cow dung gave a trouble free offloading.

Table 3: Cost analysis of the Biogas digester.

Quantity	Designation	Rate (=N=)	Total cost (=N=)
3	ø 590 mm x 900 mm drum	1,500.00	4,500.00
1	ø 80 mm x 1500 mm plastic tube	500.00	500.00
1	ø 100 mm x ø 120 mm, 90^{o} plastic joint	250.00	250.00
1	ø 10 mm x1800 mm steel rod	300.00	300.00
1	600 mm x 400 mm x 2 mm steel sheet	2,000.00	2,000.00
1	ø 24 mm x 3500 mm galvanized pipe	1,000.00	1,000.00
1	Black oil paint	450.00	450.00
1	White oil paint	400.00	400.00
16	M 10 bolts and nuts, 40 mm long	10.00	160.00
1	Tap	200.00	200.00
1	ø 8 mm x 25 mm pin	5.00	5.00
2	M 24, 90^{o} galvanized iron joint	600.00	1,200.00
1	ø 60 mm x 60 mm pipe	350.00	350.00
2	M 24, coupling joints	80.00	160.00
	Labour	2,000.00	2,000.00
	Total		13,475.00

Figure 1: Complete picture view of the biogas digester

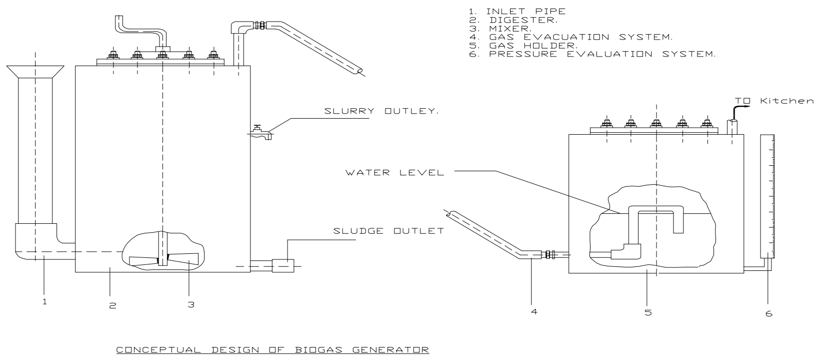

Figure 2: Conceptual design of Biogas Generator.

REFERENCES

Aarne Vesilind P., Jeffrey J. Pierce and Ruth Weiner (1988) Environmental Engineering, Butterworth-Heinemann, Stoneham USA, 2nd edition.

Abubakar M. M. (1990) Biogas generation from animal wastes, Nigerian Journal of Renewable Energy, Vol. 4, pp: 11-16.

Akinbami J. F. K., Ilori M. O., Oyebsi T. O. and Adeoti O. (2001) Biogas Energy Use in Nigeria: Current Status, Future Prospects and Policy Implications; Renewable and Sustainable Energy Reviews, Vol. 3, No. 5, pp: 97-112

Aliyu M., Dangoggo S. M. and Atiku A.T. (1996) Biogas Production from Pigeon droppings, Nigerian Journal of Renewable Energy, Vol. 4, No. 1, pp48-52

Avalone Eugene A. and Theodore Baumeister III (1996) *Mark's Standard handbook for Mechanical Engineers*. 10th. Edition Mc Graw-Hill

Compressed Gas Association (CGA) (1990) Handbook of Compressed Gases, 3rd edition, Kluver Academic Publishers, USA.

Martyn V. Twigg (1994) Catalyst Handbook, Wiley and Sons Inc., 2nd edition

Nijaguna B. T. (2006) Biogas Technology, McGraw Hill India, 2nd edition.

Peter N. Hobson and Andrew D. Wheatley (1993) Anaerobic Digestion: Modern theory and Practice; Springer-Verlag New York, LLC, pp: 355-372

Peter N. Hobson and Robertson A. M. (1999) Waste treatment in Agriculture, Elsevier Science & Technology, London, pp: 230- 243

Pickering Kevin T. and Owen Lewis A (1995) *An introduction to Global Environmental Issues*. Routledge Publishers, London

Pruss A., E. Giroult and P. Rushbrook (1999) *Safe Management of wastes from health –care activities*. World Health organization-Geneva.

Rival Pierre (2005) Finding the right mix, Energies: Ideas, Actions and People as seen by Total, No. 7, pp: 26-31 March

Syngenta Foundation for Sustainable Agriculture (SFSA) (2007) *Sustainable innovation in agriculture: A Background to The Sahel and the semiarid region*. Helika Limited, UK

World Health Organization (WHO) (2002) *Health- Care Waste Management*. October, Geneva Switzerland.

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Corresponding Author
M.B Oumarou
Mechanical Engineering Department, University of Maiduguri, Bornu State
Email: mmbenomar@yahoo.com